Patient Preference for Entry, Mid, or Advanced Level Digital Hearing Aid Technology

Audiology Capstone Project

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Audiology in the Graduate School of The Ohio State University

By

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Abstract

The motivation of this retrospective study was to determine if patient files indicated preference for advanced level hearing aid technology over mid-level and entry level technology. Fifty participants were selected from the database at The Ohio State University Speech-Language-Hearing Clinic whose hearing loss warranted amplification and who trialed different levels of technology and provided feedback on each level trialed. Forty seven patients were included in the study; eighteen of which were blinded to the level of hearing aid technology and twenty-nine who were not. Ninety-four percent of subjects in the blinded group and 90% of subjects in the not blinded group preferred the highest level of hearing aid technology they trialed. Altogether; 89% of subjects who trialed the advanced level technology preferred it to lower levels of technology and 91% preferred the highest technology level trialed. One-hundred percent of previous hearing aid users preferred the highest level hearing aid technology trialed, in comparison to 88% of new hearing aid users. In total, 17% of the blinded group and 24% of the not blinded group purchased a lower level of hearing aid technology than was preferred; 21% of the total subjects. Ninety-three percent of previous hearing aid users purchased their preference and 75% of new hearing aid users purchased their preference; 79% of all subjects in total purchased their preference.

Dedication

This capstone is dedicated to the biggest supporters of my life. To my mother, Haifa Y. Chehouri, who is the embodiment of what is a strong woman. You taught me never to settle in life and you were always and are always my biggest fan. To my father, Abdul-Hamid Alchahal, you love with all of you. My siblings: Selma Alchahal, Ali Alchahal and Faouzie Alchahal; everything we do in this life is a collaboration. Everything I am is because of you and without you there would be no me; and to a wonderful friend and companion, Bilal Jaber, you make me strive to be a better person in more ways than one. To all of you, I say thank you, because no other words are enough.

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Field of Study

Major Field: Audiology

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Chapter 1

Introduction

Prevalence of Hearing Loss

The prevalence of bilateral hearing loss is currently estimated at 30 million Americans, which is 12.7% of people aged 12 years or older. An estimated 40.1 million of Americans 12 years of age or older, or 20.1% of the population, have a unilateral hearing loss. These combined data indicate that 1 in 8 individuals have bilateral hearing loss and nearly 1 in 5 individuals have unilateral or bilateral hearing loss (Lin et al., 2011). While the United States household average grew 6.8% from 1989 to 2005, the hearing loss population grew 9.9% (Kochkin, 2005b). It is estimated that nearly 80% of individuals over the age of 75 will experience some degree of sensorineural hearing loss in the coming years (WHO, 2002).

In 2009 Kochkin addressed compliance of hearing aid use among people with hearing loss and revealed that only 1 in 10 individuals with a mild hearing loss and 4 in 10 individuals with a moderate to severe hearing loss use hearing aids. Results from Kochkin (2009) revealed only 24.6% of individuals with admitted hearing loss had adopted hearing aid use. One in four respondents in the Kochkin (2009) study reported that they believed that their hearing loss was "too mild" for hearing aids. Half of the respondents reported that they either did not need "fine-tuned" hearing for their jobs or perceived that they heard well enough in most of their listening situations without the use of hearing aids. Half of the respondents with severe hearing loss had a minimum of one negative perception about hearing aids. The most commonly cited negative perceptions in ranked order were: the inability of the hearing aids to perform in noise and restore normal hearing, the presence of acoustic feedback, the inability of the hearing aids to work in listening environments with crowds, unwanted background noise being amplified by the hearing aids, and that hearing aids in general were perceived as a "hassle." One half of the respondents of the study reported a stigma, or a feeling of disgrace or shame (Wallhagen, 2009) associated with wearing hearing aids. However, the author of this study reported that stigma may account for more than the results indicated. It was estimated than an older adult is four times more likely to accept the notion of hearing aids compared to a younger individual with the same audiogram (Kockhkin, 2004). Although 65% of people with hearing loss are under the age of 65 (Kochkin, 2005a), survey results have indicated that hearing loss is viewed as only present in the elderly and therefore only acceptable for the elderly to address the loss with hearing aids (Kochkin, 2004). Sixty-four percent of individuals surveyed in this study noted that the price of hearing aids was also a significant negative factor to obtaining hearing aids; and many of the respondents questioned the value of hearing aids.

A separate survey study completed by Kochkin (2005b) revealed that 41% of hearing aids users were unhappy with the performance of their hearing aids. The most commonly cited reasons were difficulty listening with the hearing aids in the presence of background noise and in challenging or complex listening environments. Difficulty with understanding speech in the presence of background noise is the biggest factor for not adopting a hearing aid (Kochkin, 2004) and it's the most cited reason for dissatisfaction with hearing aids (Kochkin, 2005b). The Kochkin (2005b) results revealed that subjective perception of hearing aid performance was a significant factor in hearing aid compliance and adoption. Salonen et al. (2013) also addressed hearing aid compliance with results in agreement with Kochkin (2005b), as subjects from both studies reported that the inability to distinguish between background noise and signals of interest as well as the presence of acoustic feedback were the most significant contributors of hearing aid noncompliance. Therefore, adoption of hearing aids is based, in part, on the subject's perception of hearing aid performance. It is because of these complaints that hearing aid manufacturers place much of their emphasis on developing hearing aid technology that addresses speech understanding in the presence of background noise (Kreisman et al., 2010) and the presence of acoustic feedback. Developments such as binaural synchronization, additional channels and bands, noise reduction algorithms, feedback suppression, and directional microphones are features of modern hearing aids that are designed to address the issues of speech understanding in the presence of background noise, as well as listening comfort and acoustic feedback. However, these advanced features are not present in all hearing aids. Hearing aid technology level varies in products that are offered by manufacturers; many manufacturers offer different levels of hearing aid technology. As the level of hearing aid technology increases the presence of the advanced features of the hearing aid increase as well. Since hearing aid adoption and compliance relies on the user's perception of their ability to understand speech in the presence of background noise (Kochkin, 2005b; Salonen et al., 2013), it is important to study user preference of hearing aid technology levels, as the features of more advanced levels of hearing aid technology were designed to address these complaints. The purpose of this retrospective study is to determine benefit of these additional features by determining preference of technology level among hearing aid users.

Chapter 2

Literature Review

Effects of Hearing Loss

Sensorineural hearing loss occurs when structural deficits are present in the inner ear and/or the auditory nerve. Individuals with sensorineural hearing loss may experience communication difficulties including a decrease in audibility, localization, and speech understanding (Studebaker et al., 1997). Decreased speech understanding can be a result of decreased audibility of frequencies important to speech as a consequence of the hearing loss, as well as a decrease in frequencies important to speech due to a masking effect by other present signals (Hornsby & Ricketts, 2003). However, sensorineural hearing loss is not defined merely by structural deficits in the auditory system, such as damage to the cochlea. Hearing loss impacts a patient's social, emotional, and cognitive functions (Arlinger, 2003). Older studies demonstrated that hearing loss was related to negative emotions as indicated by the results of questionnaires completed by 100 individuals with varied degrees of hearing loss (Ventry & Weinstein, 1982). More recent studies, such as Dalton et al. (2003) described the effect of hearing loss on individuals in regards to hearing handicap, communication difficulties, and health related quality of life. Results revealed that hearing loss was related to decreased quality of life. These data indicated that hearing loss is a major chronic condition in the lives of many people and although there are no current medical or surgical treatments for most cases of sensorineural hearing loss, audiologic involvement, including amplification in the form of hearing aids, is not only available, but important (Chisolm et al, 2007).

Hearing Aids

The goal of hearing aid use is to help compensate for communication and listening difficulties that result from hearing loss. When a hearing loss is present certain quiet sounds may be inaudible to the listener and other sounds cannot be discriminated from each other (Dillon, 2001). Traditionally, hearing aids used an analog processing scheme to amplify and shape signals. Currently, most hearing aids utilize a processing scheme called Digital Signal Processing, or DSP, which converts the analog signal into a stream of numbers for flexibility in shaping the signal. Hearing aids can be categorized as either being analog, where the analog schematic is utilized, or digital, where DSP is utilized. In hearing aids that utilize the analog schematic, the signal is processed in a signal pathway. The signal pathway contains smaller circuits called signal blocks that are attached to a control, or potentiometer, on the outside casing of the hearing aid. The audiologist would use the controls to shape the signal in different ways. Many analog hearing aids offered a very limited number of potentiometers. The electrical stimulus would then be processed through the receiver of the hearing aid where it would be converted back into an acoustic signal that could be delivered to the listener. In contrast to the analog signal processing scheme, the DSP processing scheme digitizes the incoming signal which allows for it to be more closely represented. Digital hearing aids do not shape the electrical stimuli with signal blocks; the analog signal is converted into binary code in what is called an *analog to digital converter.* The string of numbers is then delivered to the digital signal processor where the numbers can be manipulated; the digital signal processor can be thought of as a different type of signal pathway. Instead of using signal blocks to manipulate the signal, the now converted signal can be separated into its composing frequencies and manipulated in different compression channels which are preset in the hearing aid by the audiologist using software from the manufacturer of the hearing aid. A compression channel, or channel, is defined as the frequency range in the digital filter of the hearing aid (Stone et al., 2008). The use of channels in different hearing aid technologies and the goal of more closely matching a user's hearing loss (Kim & Barrs, 2006) will be discussed in detail later in chapter two. After the converted signal is separated into its composing frequencies and manipulated in its corresponding channel according to the settings of the hearing aid, the signal is then recombined and converted back into an analog signal in the *digital to analog converter* of the hearing aid. It is because the digital hearing aid converts the analog signal into a string of numbers that the signal can be manipulated in an endless number of ways (Dillon, 2001). This added flexibility in manipulation of the signal allows for better signal processing (Banerjee & Garstecki, 2003) as it provides greater flexibility in adjusting the frequency response of the original signal to more closely match the hearing aid user's hearing loss (Chang et al., 2007). The differences in processing schematics are depicted in Figure 1.

A

B

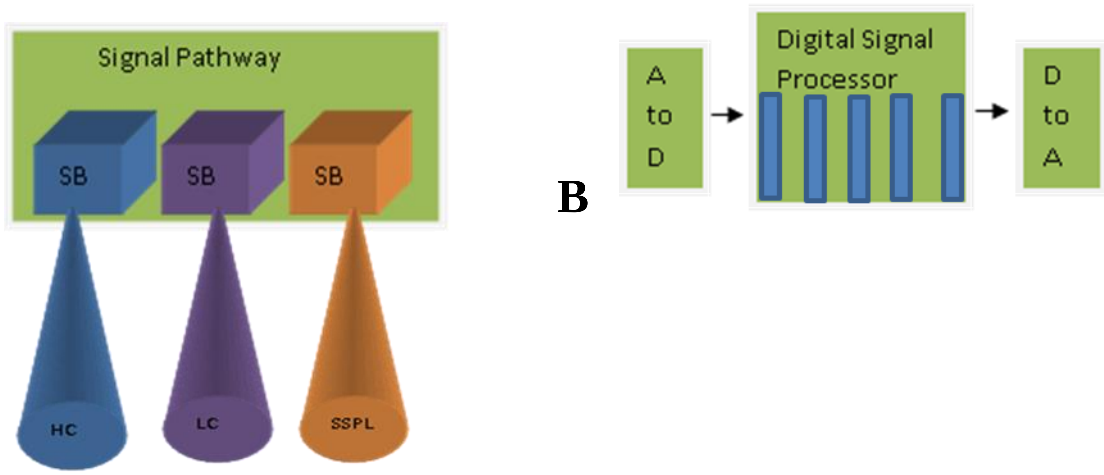

Figure 1: Analog vs. Digital processing schematics. Figure1 A: Analog processing schematic. The electrical stimuli are shaped in different signal blocks encased in the signal pathway. The audiologist can shape the signal by using potentiometers, such as the high cut (HC), low cut (LC), and maximum output (SSPL). **Figure1 B:** Digital signal processing schematic. The electrical stimuli are converted into a binary code in the analog to digital converter (A to D), shaped in corresponding channels encased in the digital signal processor, and converted back into an analog signal in the digital to analog converter (D to A).

The sound quality of digital hearing aids was addressed in a study by Arlinger et al. (1998) where subjects who utilized analog hearing aids were fit with digital hearing aids for a period of one month. Subjective measures reported by participants indicated a statistically significant preference for the digital hearing aids over the analog hearing aids with the biggest difference noted with improved speech communication and the impact of the use of digital hearing aids on social relations (Arlinger et al., 1998).

Hearing Aid Benefit

The benefit of hearing aid use for those with a hearing impairment has been well established and hearing aids are a well-accepted audiologic treatment for hearing loss. The National Council of Aging completed a study to determine the result of hearing aid use on the effects of hearing loss in older adults by having a questionnaire completed by individuals with hearing loss who either used hearing aids or did not (Seniors Research Group, 1999). Results revealed that signs of paranoia and depression were reported more often by non-hearing aid users. Hearing aid users and their significant others reported better communication and relationships at home.

The recommendations of the American Academy of Audiology task force on the benefits of amplification were in agreement with previous findings of hearing aid benefit (Chisolm et al., 2007). The task force performed a meta-analysis of different studies that measured the benefit of hearing aid use. Reduced anxiety and depression when individuals with hearing loss consistently used hearing aids was found in several studies (Joore et al., 2002; Joore et al., 2003) and subjects also reported an improvement in social functioning after being fit with hearing aids (Joore et al., 2003). A quantitative review of the studies also revealed a significant improvement in hearing related quality of life measures.

Clearly, individuals who have hearing loss receive benefit from amplification, and studies have revealed that regardless of manufacturer of the hearing aid (Harnack Knebel

& Bentler, 1998) or fitting strategy used (Metselaar et al., 2009), individuals with hearing loss benefit from hearing aids. All manufacturers of hearing aids offer different levels of technology. It is important to define the features found in different levels of technology and to determine user preference of these levels of technology with individuals who have hearing loss; as compliance of hearing aids is dependent on user perception (Kochkin, 2004).

Levels of Hearing Aid Technology

Digital hearing aids are typically offered in three different circuitries: entry-level, mid-level, and advanced level technology. Current hearing aid technology offers many features such as channels and bands, feedback suppression, noise reduction, and binaural wireless synchronization. The general purpose of all of these features are to increase speech understanding in the presence of background noise (Kreisman et al., 2010) and reduce the presence of acoustic feedback as these are the most common complaints of hearing aid users (Kochkin, 2004; Kochkin, 2005b; Salonen et al., 2013). These features increase in functionality as the level of hearing aid technology increases.

Channels and Bands

The terms *channel* and *band* are often used interchangeably; however, they are defined as two very different features of a hearing aid. A compression channel, or channel, is defined as the frequency range in the digital signal processor, also known as the digital filter, of the hearing aid while bands are the number of adjustment levers provided to the audiologist in the programming software (Stone et al., 2008). A channel is considered to be the part of the digital signal processor where the signal is separated into frequency groups where shaping occurs, based on the settings of the hearing aid. Most signals entering the hearing aid are not pure tones, as most sounds are comprised of many different frequencies. The filter is designed to deconstruct the inputs of the microphone into their composing frequencies. The parts of the signal are then placed in a corresponding channel where it will be determined how much gain should be applied, based on the settings of the hearing aid and the input signal. The more channels available in the hearing aid, the more closely the original signal can be replicated. (Galster & Galster, 2011).

In contrast to channels, bands, or frequency bands, are controls in the manufacturer's software that are available for the audiologist to manipulate according to the listener's hearing loss. The greater number of frequency bands available in the hearing aid, the greater flexibility the hearing aid offers to more closely match the patient's audiogram, which can result in increased audibility due to the distribution of amplification (Galster & Galster, 2011). As the level of technology in digital hearing aids is increased, the number of frequency bands is increased as well. More frequency bands may also result in better feedback management without straying too far from prescriptive targets. Feedback is a whistling or ringing sound that is caused by the hearing aid that can be audible to the hearing aid user (Johnson et al., 2007) and individuals around them while prescriptive targets are amplification goals set for the patient. Additional bands in a hearing aid allow the audiologist to reduce the amount of amplification in one frequency band that may be responsible for causing feedback without affecting another band that may be more important for speech understanding (Galster & Galster, 2011). Aahz and Moore (2007) addressed the effect of number of frequency bands on fitting accuracy along with the ability to control feedback. The results of this study found that seven frequency bands were needed for sloping hearing losses, which make up the majority of hearing losses encountered when fitting hearing aids (Galster & Galster, 2011).

Feedback Suppression

Twenty-four percent of hearing aid users complain of acoustic feedback with their hearing aids (Kochkin, 1997; Kochkin, 2003) and concerns about experiencing acoustic feedback is one of the most commonly cited reasons for not getting a hearing aid (Kochkin, 2004; Kochkin, 2005b; Salonen et al., 2013) Feedback occurs when a signal is picked up by the microphone, digitized, amplified, and reconverted into an acoustic signal, then rather than being delivered to the user, it is re-entered into the microphone and amplified. This results in an audible “whistle.” Currently, all hearing aids that utilize a DSP employ some form of acoustic feedback reduction algorithms to reduce feedback, either by using a form of phase cancellation or a filtering system (Johnson et al., 2007; Chung 2004b).

Filtering, also referred to as notch filtering, reduces the gain in the frequency band from which the feedback is being caused (Agnew 1996; Johnson et al., 2007). Although this is a successful strategy in reducing the amount of feedback, it often resulted in decreased audibility to the listener, generally in the higher frequencies that contribute to overall speech understanding, as feedback typically occurs between 2 kHz-5 kHz. (Kates, 1999; Johnson et al., 2007). Therefore, reducing the higher frequencies may also result in a reduction in speech understanding for the listener. A second form of feedback cancellation uses Fast Fourier transform to reduce the amount of feedback, and it is more commonly used in higher level technology hearing aids. The goal of this form of feedback reduction is to minimize the presence of feedback by effectively cancelling it with another signal of the same amplitude that is 180 degrees out of phase with the feedback signal. An advantage of more advanced feedback suppression systems is that they are constantly monitoring the changes of the feedback path which could result in better speech understanding (Latzel et al., 2002, Chung, 2004b), rather than simply reducing the amplification in the frequency band where the feedback is being caused.

Noise Reduction

Listening in the presence of background noise is a challenge for people with hearing loss due to the loss of important speech cues and the masking effect that can be caused by other present noises (Hornsby & Ricketts, 2003). Hearing aids with DSP utilize several approaches to minimize the impact of background noise from impeding speech understanding; including directional microphones and noise reduction algorithms (Chung, 2004a).

Directional Microphones

Adaptive directional microphones, a feature in current digital hearing aids, have been identified as one of the best methods to improve the signal-to-noise ratio, the intensity ratio of the signal of interest to present background noise, secondary only to personal FM systems that use remote microphone systems (Chung, 2004a). Sensitivity regions vary in adaptive directional microphones, depending on the listening environment; that is, the microphone's maximum area of sensitivity changes depending on the listening environment; it will not be equally sensitive to sounds coming from every direction. Although the hearing aid microphone will often place priority on the signal in front of the listener (Kuk et al., 2002a), the goal of this directional microphone strategy is to reduce noise regardless of its originating location. Unfortunately, if there are several noise sources present, the least sensitive portion of the microphone may not be directed to the loudest noise source (Bentler et al., 2004). Higher levels of digital hearing aid technology employ multichannel adaptive directional microphone schematics. Multichannel adaptive directionality allows for different sensitivity patterns to occur in multiple channels simultaneously which can offer greater audibility of speech signals from varying frequencies (Chung, 2004a). This is achieved by utilizing different delay times in separate channels. The aim of multichannel adaptive directionality is to reduce noise present with different frequency contents; therefore, the more channels that are present the greater noise reduction available. This may effectively solve the problem of several noise sources, given the noise sources are of different frequency content.

Noise Reduction Algorithms

Another form of noise reduction in digital hearing aids is noise reduction algorithms. The goal of a noise reduction algorithm is to reduce the impact of noise interference on speech understanding, as it is a primary complaint of hearing aid users (Kochkin, 2005b; Salonen et al., 2013). Although most noise reduction algorithms are proprietary to the manufacturer of the hearing aid, modulation detection of the incoming signal is a consistent component in all algorithms. The modulation of the signal, or rate of fluctuation of the signal, is used to determine the presence (or absence) of a speech signal, since the modulation rate for speech is different from that of noise. Most hearing aids have a multi-channel adaptive noise reduction algorithm, reducing the gain in the frequency channel(s) in which the noise occurs. Thus, having a greater number of channels is a benefit in this type of noise reduction system. This is a possible limitation of a hearing aid with fewer channels, such as with entry-level hearing aid technology. For example, consider a hearing aid with 3 channels where a noise reduction algorithm is employed; the reduction of amplification where noise occurs can also reduce amplification of important speech information, if the noise and signal share the same channel. A hearing aid with a greater number of channels may be less affected by this as fewer frequencies that are not related to the noise are decreased (Chung, 2004a), possibly improving the hearing aid sound quality and compliance rate.

Binaural Wireless Synchronization

There are significant benefits to binaural hearing, one of the most important being localization of sound (Brown and Balkany, 2007; Firszt et al., 2008). Localization of sound is the ability of the auditory system to perceive where a sound source is located in space. Sounds will reach one ear first, given that the sound source is not at 0 degrees or 180 degrees in the horizontal plane. The auditory system in an individual with normal hearing is able to make use of time and intensity differences of the signal between the ears to determine the sound source's location in space (Yost and Dye, 1988). Listeners with hearing loss have a decreased ability to localize sound due to their decreased sound sensitivity (Firszt et al., 2008); therefore, current hearing aid technology utilizes binaural synchronization, the ability to synchronize processing between two hearing aids. Regaining this feature of the auditory system is attempted by offering communication between the two hearing aids; however, the communication abilities of hearing aids vary between different levels of technology. Hearing aids with entry-level technology provide synchronization between the two hearing aids in the form of volume and program control, improving the convenience of the hearing aid. Typically, the mid-level hearing aid technology with binaural synchronization will have this capability along with the added feature of synchronized noise reduction and directionality, with the goal of improving speech in the presence of background noise. The advanced level hearing aid technology with binaural wireless communication will have all of the aforementioned features, with the added feature of synchronized compression. Compression is the ability of the hearing aid to change the amount of amplification given based on the input level of the signal as well as the frequency channel. Synchronized compression, or coordinated compression, is the wireless feature of the advanced-level hearing aid that alters compression based in part on the level differences of inputs between the hearing aids (Ernst et al., 2013). The compression features of the hearing aids communicate, adjusting according to the level of the input and frequencies received, with the goal of increasing the clarity and naturalness of speech and improving sound localization (Sockalingam et al., 2009).

As evidenced by previous studies, two of the most commonly cited reasons for hearing aid noncompliance are the continued difficulty of understanding speech in the presence of background noise and the presence of acoustic feedback (Kochkin, 2005b; Salonen et al., 2013). It is because of these complaints that manufacturers of hearing aids continue to offer advances in technology (Kreisman et al., 2010), including advanced level hearing aid technology features. The aim of the present study is to determine preference for hearing aid technology levels to determine benefit from these added features.

Rationale for Patient Preference

Health professionals are expected to demonstrate that their services and treatments are beneficial and have a positive impact on their patient's quality of life (Uriate et al., 2005). This is true for audiologists, as hearing impairment can have social and emotional impacts on an individual. Therefore, audiologists perform a method of validation, known as outcome measures, to assess treatment efficacy (Mendel, 2009) where treatment efficacy is defined as benefit from hearing aids in speech intelligibility and quality of life. Validation helps to determine if patients receive benefit from amplification and it can also provide information in regards to benefit from different models or styles of hearing aids or different levels of technology. Validation can be completed using aided testing vs. unaided testing to determine improvement in speech intelligibility, and with more subjective outcome measures to determine patient perception of benefit and preference.

Functional Testing

Varying levels of hearing aid technology and their functional benefit have been measured in several studies. Newman and Sandridge (1998) addressed the benefit of different technology levels with speech-in-noise testing, and results indicated a difference in speech perception scores with three different technologies of hearing aids; however, the differences in scores were minimal and results did not indicate that the differences in speech intelligibility scores between these levels would equate to improved performance in real world listening environments. More recent studies have also measured the effect of hearing aid technology level on speech recognition in noise. Schum and Bruun Hanson (2007) studied coordinated compression, known in the Oticon products as *Spatial Sound*. Although an increase in the level difference between the ears was noted when a hearing aid with Spatial Sound was used, the effect this difference had on speech recognition scores was not recorded. Also, the noise source in this study was a white noise presented from one location, which is not a reflection of real world listening environments.

A more recent study completed by Kreisman et al. (2010) addressed coordinated compression and the effect it had on speech understanding in the presence of background noise. Thirty six subjects with a mean age of 64.5 years were tested for benefit using two hearing aids: the Epoq XW or Syncro hearing aids, the former having coordinated compression. After an adaptation period, improvement was measured using speech in noise tests. Subjects were then switched to the second set of hearing aids and retested. Speech-in-noise testing was completed in each condition and results indicated that scores improved when comparing the Epoq XW aided condition to the Syncro aided condition. This indicated that the hearing aid with coordinated compression provided additional benefit. However, there was no clear determination that the added benefit was from coordinated compression. The added benefit could simply have been a better signal processor, which does not provide information specifically on coordinated compression. Secondly, the signal of interest in this study was presented at 0 degrees azimuth, which is not always an accurate representation of real world listening environments. These limitations indicate that advanced level digital hearing aid features and the influence they may have on user preference cannot, to date, be accurately accessed using audiometric data alone. It is therefore important to consider self-reported information of preference.

Since audiologists are required to demonstrate that the treatment options they offer to their patients provide benefit (Uriate et al., 2005) and the benefit of advanced level digital hearing aid technology features cannot be assessed audiometrically in a manner that equates to real world listening, subjective measures should be considered routinely. Subjective measures of benefit from amplification in addition to objective measures are beneficial as hearing aid compliance is dependent, at least in part, on patient perception of hearing aid benefit. Although functional testing of hearing aids can provide the audiologist with important information about the hearing aid settings, real world situations cannot be accurately demonstrated in a sound treated booth in a clinical setting. There are procedural variables, such as inter-and intra-subject variability, partial vs. full list used in word/sentence recognition scores, phonetic balancing, as well as the use or nonuse of a carrier phrase, that are thought to be limitations of research using speech perception scores (Mendel, 2009). Therefore, subjective outcome measures often provide a more direct way of assessing treatment efficacy in hearing aids (Mendel, 2009). Subjective outcome measures also offer the ability to measure user preference and the opportunity for audiologists to look closely at their routine clinical practices and procedures to determine room for improvement (Beck, 2000). One example of a subjective outcome measure is the *Client Oriented Scale of Improvemen*t (COSI), a measure of treatment efficacy of hearing aids (Dillon et al., 1997). In the COSI, hearing aid users are asked to list five specific situations where they would like to improve their hearing abilities and to rate these situations in order of what is most important to them, which was performed before and after fitting of amplification. The COSI is beneficial for several reasons; it is non-invasive, it addresses how well the user is coping with their problems, and it requires hearing aid candidates to offer situations in which they perceived difficulty. In other words, to use the COSI the individual must acknowledge that they have difficulty hearing. Hearing impaired individuals have been reported to have better hearing aid compliance when they believe they have difficulty hearing (Kochkin, 2005b; Salonen, 2013). The goal of this retrospective study was to determine preference between three different levels of hearing aid technology and its relationship to purchases of hearing aids, by using information obtained on COSIs in patient files.

Chapter 3

Methods

Materials

This retrospective study reviewed files of patient's who participated in a hearing aid demonstration program provided at The Ohio State University Speech-Language-Hearing Clinic from September 2008 to October 2011. The hearing aid demonstration program implemented at The Ohio State University Speech-Language-Hearing Clinic allowed patients to trial different levels of digital hearing aid technology at no charge to the patient. Oticon, a manufacturer of hearing aids, is the most dispensed manufacturer in the clinic and the hearing aid technology dispensed include entry-level, mid-level and advanced level hearing aids, in what will be considered as two generation groups of products. Generation 1 hearing aids were considered the Hit Pro, Vigo Pro, and the Epoq XW. Generation 2 hearing aids were the Ino Pro, Acto Pro, and Agil Pro. Both generations of hearing aids were classified into three different levels of digital hearing aid technology. The entry-level hearing aids were the Hit Pro and the Ino Pro, the mid-level hearing aids were the Vigo Pro and the Acto Pro, and the advanced level hearing aids were the Epoq XW and the Agil Pro. The differences between the generation 1 and generation 2 hearing aids are not addressed in this study, as these differences are equivalent among the different levels of hearing aid technology.

Outcome Measure

As routine clinical practice at The Ohio State University Speech-Language-Hearing Clinic, hearing aid candidates were provided with the opportunity to demonstrate different levels of digital hearing aid technology for up to thirty days at no cost other than the cost of custom earmolds, if recommended based on the severity and configuration of the hearing loss, and the investment of their time. In the hearing aid demonstration process, hearing aid candidates were provided with the opportunity to demonstrate any and all levels of digital hearing aid technology. They were also offered the opportunity to be “blinded” to the level of technology, therefore not being aware of the level of technology they were trialing. Hearing aid candidates who participated in the demonstration program were fit with the first level of technology available of the levels they opted to demonstrate in a style appropriate to the severity and configuration of their hearing loss. Hearing aid candidates were able to try each level of hearing aid technology they chose for up to 30 days with at least one follow-up appointment. Additional appointments were provided at the candidate’s request. During the trial period, validation of the hearing aid was typically completed via speech-in-noise testing as well as aided thresholds. Clinical practice was that adjustments to the hearing aid settings were completed based on results of aided testing and the hearing aid candidate’s observations. The COSI was also typically administered to the patient for every level of digital hearing aid technology demonstrated to allow the candidate and the audiologist to address any hearing concerns. Once the hearing aid trial period was complete, the trial of a different level of technology began. The determination of user preference of different levels of digital hearing aid technology was to be determined in this retrospective study by using the COSI results from participants' of the hearing aid demonstration program files. Unfortunately, COSI information was either not obtained or stored in every file for every level of hearing aid technology. Therefore, subject files were accessed to review COSI forms and/or any indication of preference of hearing aid technology as well as level of technology purchased.

Protocol

Fifty patient files were obtained from The Ohio State University Speech-Language-Hearing Clinic's database of patients who participated in the hearing aid demonstration program. Three of the fifty files selected were excluded from the study, as these files were of patients who tried only different generations of digital hearing aids, not different levels of digital hearing aid technology. A total of forty-seven patient files were selected for data analysis of this retrospective study. The age range of individuals with hearing loss whose files were selected in this study was between 22 and 93 years of age, with a mean age of 65.7 years. Pure tone averages ranged from 5 dB HL to 75 dB HL with a mean PTA of 37 dB HL. Fifteen of these individuals were previous hearing aid users. Thirty of the patients whose files were selected for this retrospective study were fit with behind-the-ear hearing aids while seventeen were fit with receiver-in-the-ear hearing aids, two of whom were fit with custom made earmolds coupled to the receiver portion of the hearing aid. All forty-seven subjects were fit binaurally. Twenty-eight of the patients whose files were selected for this retrospective study were male and nineteen were female. Subject files were accessed to review COSI forms and/or any additional indication of preference of hearing aid technology as well as level of technology purchased.

Chapter 4

Results

Preference

Patient files that were selected for data analysis in this retrospective study were separated into two groups: blinded, those files of patients who opted to participate in the demonstration process at The Ohio State University blinded to the level of hearing aid technology being trialed; and not blinded, those files of patients who participated in the demonstration program knowing of what level of hearing aid technology they trialed. Of the forty-seven patient files that were selected for this retrospective study.

Blinded

A total of eighteen of the forty-seven patient files included in this retrospective study were categorized as blinded, eight of which were previous hearing aid users. Three of the eighteen files in this category indicated that the subjects demonstrated all three levels of hearing aid technology and 100% preferred the advanced level of technology. Eleven subjects tried the advanced and mid-levels of technology. Ten of them (91%) preferred the advanced level of technology while only one subject (9%), preferred the mid-level technology. The subject in this group that preferred the mid-level hearing aid technology reported on the COSI that the advanced level of technology provided clearer speech; but that the harshness of the mid-level hearing aid sound quality was preferred.

Two subjects demonstrated the advanced and entry-levels of technology, 100% reporting preference for the advanced level technology. Two subjects demonstrated the mid and entry-levels of hearing aid technology, and 100% preferred the mid-level hearing aid technology. Nineteen percent of subjects who trialed the mid-level hearing aid technology preferred it; however, 67% of these subjects did not trial the advanced level technology. One hundred percent of previous hearing aid users in this category preferred the highest level of hearing aid technology they trialed, while 90% of new hearing aid users preferred the highest level of hearing aid technology they trialed. For subjects from whom the COSI was obtained, the most common reason for reporting preference for higher levels of hearing aid technology was an increase in clarity of speech in the presence of background noise/difficult listening environments. Ninety-four percent of subjects who tried the advanced level hearing aid technology preferred it, and 94% preferred the highest level of hearing aid technology they trialed. Table 1 lists subject preference from each trial group in the blinded category numerically while Figure 2 displays it graphically.

	Entry	Mid	Advanced
Group A **N=3**	0	0	3 (100%)
Group B **N=11**	N/A	1 (9%)	10 (91%)
Group C **N=2**	0	N/A	2 (100%)
Group D **N=2**	0	2 (100%)	N/A

Table 1: Blinded Subject Preference. The blinded category included four groups: **Group A**: demonstrated every level of hearing aid technology, **Group B:** demonstrated the advanced and mid-levels, **Group C**: demonstrated the advanced and entry-levels and **Group D**: demonstrated the mid and entry-levels of technology. Preference is listed numerically and in percentages.

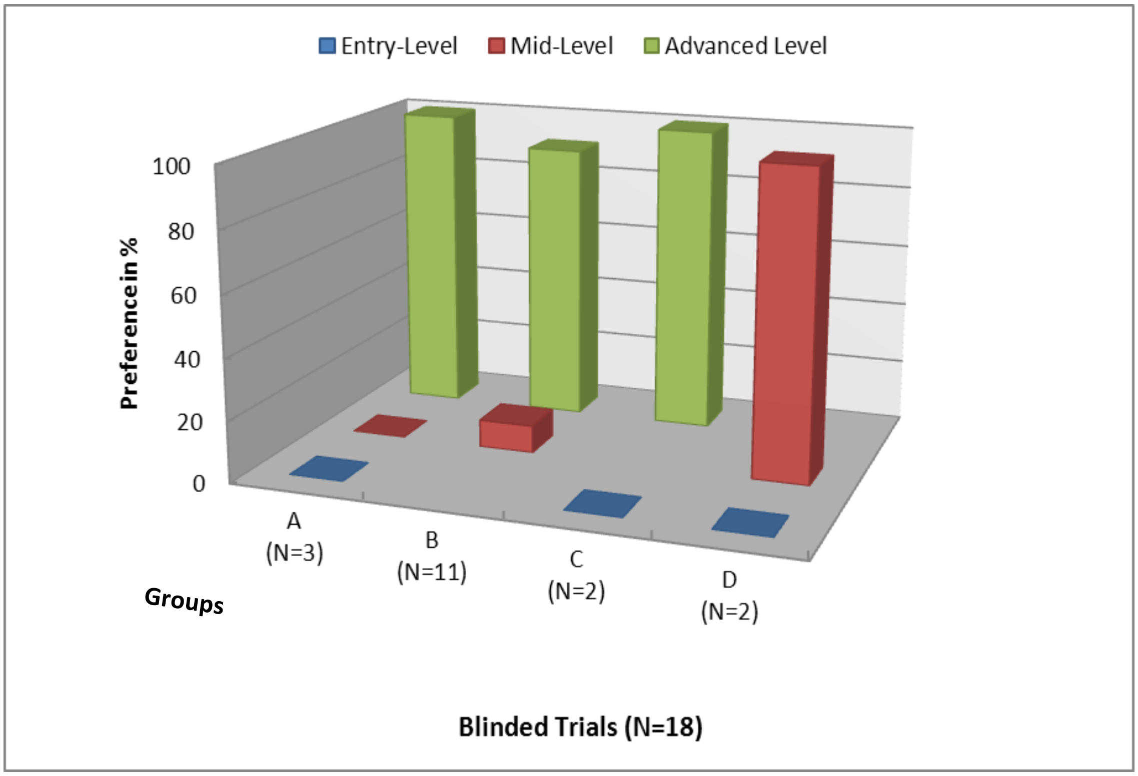

Figure 2: Blinded Subject Preference. The blinded category included four groups: **Group A**: demonstrated every level of hearing aid technology, **Group B**: demonstrated the advanced and mid-levels, **Group C**: demonstrated the advanced and entry-levels and **Group D**: demonstrated the mid and entry-levels of technology.

Not Blinded

Of the twenty-nine files in the not blinded group, seven subjects were previous hearing aid users and twenty-two were new hearing aid users. Four subjects tried all three levels of technology and 100% of these subjects preferred the advanced level technology. Eleven subjects tried the advanced and mid-level hearing aids; nine of which preferred the advanced level hearing aid technology (82%) and two preferred the mid-level hearing aid technology. Of the two subjects who reported preference for the mid-level hearing aid technology, one indicated that preference for the mid-level hearing aid because music was more enjoyable. The second subject reported liking the “harshness” of the sound in the mid-level in comparison to the advanced level technology. Three patient files indicated trial of the advanced and entry level technologies; two subjects reported preference for the advanced level (67%) and one preferred the entry-level hearing aid. The subject preferring the entry-level hearing aid over the advanced level hearing aid reported that the quality of sound from both levels of hearing aid technology were based on cost, not just the sound quality of the amplified signal. Eleven subjects trialed the mid and entry-levels of technology, and 100% preferred the mid-level hearing aid technology. Seven subjects in this category were previous hearing aid users. One hundred percent preferred a more advanced level of hearing aid technology, while 86% of new hearing aid users preferred the highest level of hearing aid technology trialed. Fifty percent of subjects who trialed the mid-level hearing aid technology preferred it; however, 85% of these subjects did not trial the advanced level hearing aid. Eighty-three percent of subjects who trialed the advanced level of hearing aid technology preferred it, and 90% preferred the highest level of hearing aid technology they tried. The most commonly cited reason for preferring a higher level of technology was a perception of clearer sound quality and better speech understanding in noise/difficult listening environments. Table 2 lists subject preference from each trial group in the not blinded category while Figure displays it graphically.

	Entry	**Mid**	**Advanced**
Group A **N=4**	0	0	4 (100%)
Group B **N=11**	N/A	2 (18%)	9 (82%)
Group C **N=3**	1 (33%)	N/A	2 (67%)
Group D **N=11**	0	11 (100%)	N/A

Table 2: Not Blinded Subject Preference. The not blinded category included four groups: **Group A**: demonstrated every level of hearing aid technology, **Group B**: demonstrated the advanced and mid-levels, **Group C:** demonstrated the advanced and entry-levels and **Group D**: demonstrated the mid and entry-levels of technology. Preference is listed numerically and in percentages.

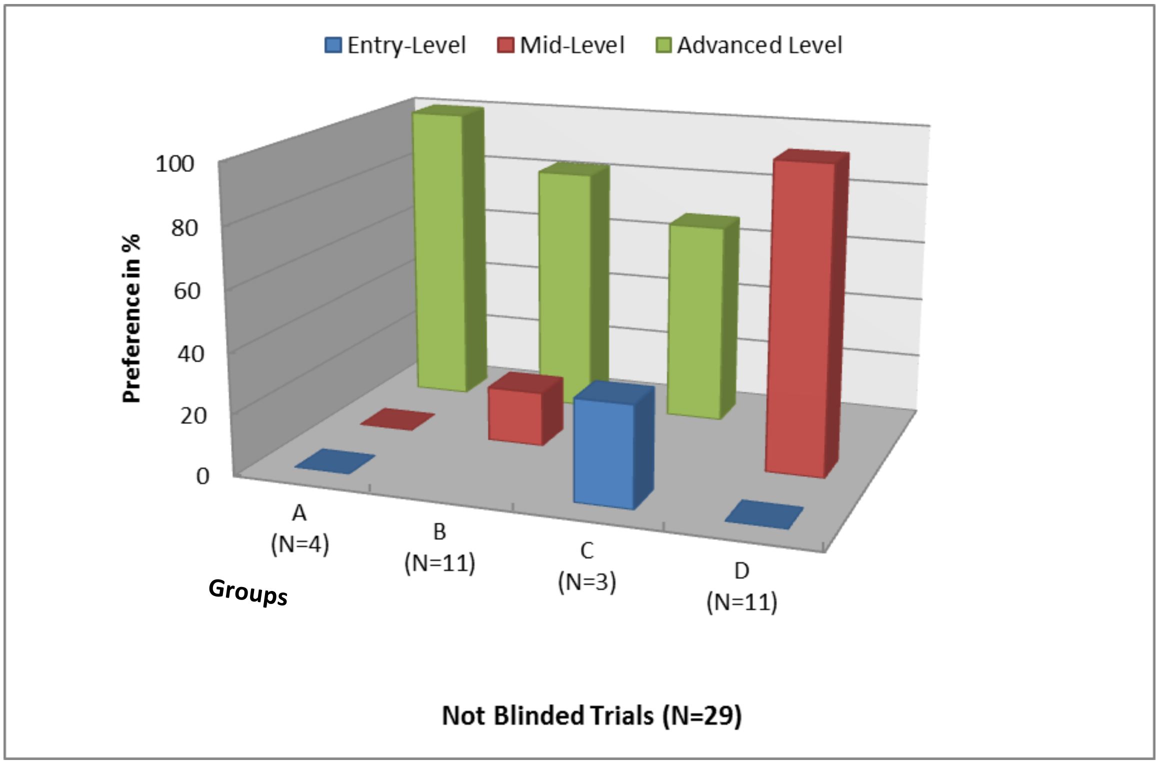

Figure 3: Not Blinded Subject Preference. The not blinded category included four groups: **Group A**: demonstrated every level of hearing aid technology, **Group B**: demonstrated the advanced and mid-levels, **Group C:** demonstrated the advanced and entry-levels and **Group D**: demonstrated the mid and entry-levels of technology.

Total Preference

In total, thirty-five subjects trialed the advanced level hearing aid technology, and thirty-one preferred it (89%) and forty-three out of the forty-seven subjects (91%) preferred the highest level of hearing aid technology they trialed. One-hundred percent of previous aid users preferred the highest level of hearing aid technology trialed, while 88% of new hearing aid users preferred the highest level trialed. In total, 38% of subjects who trialed the mid-level hearing aid preferred it; however, 81% of these subjects did not trial the advanced level hearing aid. Table 3 and Figure 4 display the overall total subject preference data in two ways, numerically and graphically.

	Entry	Mid	Advanced
Group A **N=7**	0	0	7 (100%)
Group B **N=22**	N/A	3 (14%)	19 (86%)
Group C **N=5**	1 (20%)	N/A	4 (80%)
Group D **N=13**	0	13 (100%)	N/A

Table 3: Total Subject Preference. **Group A**: demonstrated every level of hearing aid technology, **Group B:** demonstrated the advanced and mid-levels, **Group C**: demonstrated the advanced and entry-levels and **Group D**: demonstrated the mid and entry-levels of technology. Preference is listed numerically and in percentages.

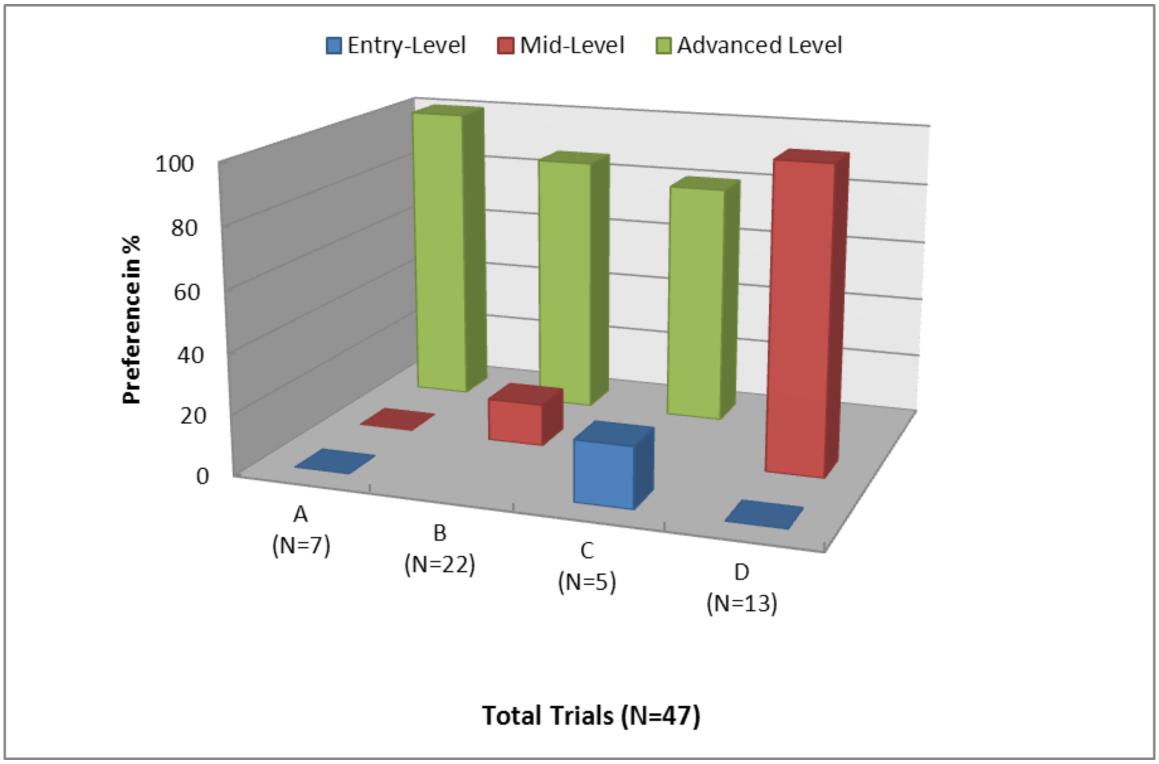

Figure 4: Total Subject Preference. **Group A**: demonstrated every level of hearing aid technology, **Group B:** demonstrated the advanced and mid-levels, **Group C**: demonstrated the advanced and entry-levels and **Group D**: demonstrated the mid and entry-levels of technology.

Purchases Blinded

Purchases were found to be different from subject preference. Of the blinded category, 100% of subjects who demonstrated all three levels of hearing aid technology preferred and purchased the advanced level. Ninety-one percent of subjects who trialed the advanced and mid-levels of hearing aid technology preferred the advanced level hearing aid technology, 90% of whom purchased advanced. The 10% (one subject) who did not cited cost as the primary deciding factor. The one subject who preferred the mid-level to the advanced level hearing aid purchased the mid-level hearing aid technology. One hundred percent of subjects who trialed the advanced and entry-levels of hearing aid technology preferred the advanced level; however, only 50% (1 subject) purchased it. The other purchased entry level hearing aid technology, citing cost as the primary deciding factor. Of the two subjects who trialed mid and entry-levels of technology, 100% preferred the mid-level technology; however, only 50% (1 subject) purchased it. Of the eight previous hearing aid users, 88% purchased their preference and 80% of new hearing aid users purchased their preference. Again, cost was cited as the primary reason for all purchases of lower level technology than the preference.

Purchases Not Blinded

Of the subjects who were not blinded, four subjects trialed all three levels of hearing aid technology, and 100% preferred the advanced technology. However, none of these subjects purchased it; 25% did not purchase any hearing aids, 25% purchased mid-level technology, and 50% purchased entry-level hearing aid technology. All subjects cited cost as the primary reason. Of the subjects who trialed the advanced and mid-levels of technology, 82% preferred the advanced level hearing aid technology, 78% of which purchased it. The remaining 22% that preferred the advanced level technology purchased mid-level technology. The two subjects in this group who preferred the mid-level hearing aid to the advanced purchased mid-level technology. Of the three subjects who trialed advanced and entry-level technology, 67% preferred the advanced level technology, 100% of which purchased it. The 33% who preferred the entry over advanced level technology purchased entry-level hearing aids. Of the eleven subjects who trialed the mid and entry-levels of technology, 100% preferred the mid-level and all but one (9%) purchased it. One subject who trialed entry and mid-levels of technology reported that although cost was a significant factor in the decision to purchase hearing aids, the differences between the entry and mid-levels of technology were clear an warranted the cost. Two subjects in this group opted to purchase one hearing aid, citing cost as the deciding factor; one purchased a lower level of hearing aid technology. A total of 86% of previous hearing aid users 77% of new hearing aid users in this category purchased their preference. All subjects who purchased a lower level of hearing aid technology than their preference reported cost as a significant factor.

Total Purchases

In total, 17% of the blinded group and 24% of the not blinded group purchased a lower level of hearing aid technology than was preferred; 21% of the total subjects. Ninety-three percent of previous hearing aid users (14 out of 15) and 75% of new hearing aid users (24 out of 32) purchased their preference, and 79% of all subjects purchased their preference. The most commonly cited reason for purchasing a low level of hearing aid technology was the issue of cost.

Chapter 5

Conclusions

Several interesting observations were made with the data obtained in this retrospective study; 91% of total subjects preferred the highest level of technology demonstrated, and 89% of total subjects who tried the advanced level hearing aid technology preferred it. The blinded group and not blinded group were very similar in that 94% of the blinded group and 90% of the not blinded group preferred the highest level of hearing aid technology that was trialed. These data indicated that regardless of knowledge about hearing aid technology being trialed, subjects preferred higher levels of technology; even when they knew the cost. Although the exact benefit that advanced level hearing aid technology provides cannot be audiometrically measured, a clear documentation of preference for it was made. Although improvement could not be measured in terms of COSI data between the levels of technology, the majority of subjects found enough benefit from the higher levels of hearing aid technology they trialed to purchase it, therefore indicating that the benefit was great enough to warrant the cost. Also, it can be argued that preference alone is enough to warrant advanced level hearing aid technology, as research has shown that hearing aid candidates and users report that hearing aid compliance is depended on perceived benefit of hearing aids (Kochkin, 2005b; Salonen et al., 2013). Thus, if a preference is made for a higher level of hearing aid technology, and this technology is dispensed, hearing aid compliance may improve.

Another interesting indication of these data is that 100% of subjects in this retrospective study who were previous hearing aid users preferred a higher level of hearing aid technology and all but one purchased it. One previous hearing aid user reported that hearing was “much less work” with the advanced level technology, while another reported that sound quality with a higher level of hearing aid technology was “much clearer in noise,” when compared to an entry-level hearing aid. A third previous hearing aid user reported that although cost was a significant concern, the decision to purchase a higher level of hearing aid technology was based on the significant clarity reported with the higher technology level. The one previous hearing aid user who did not purchase their preference did not purchase hearing aids at all; reporting that although the advanced level hearing aid technology was preferred, the benefit in comparison to his own hearing aids did not warrant the cost of new hearing aids.

Four subjects included in this study preferred a lower level hearing aid technology, in comparison to other levels trialed; all four were new hearing aid users, and three were under the age of 65. This brings to the forefront a question regarding patient acceptance of hearing loss and perception of hearing aid value. Hearing loss is often viewed as an elderly condition, even though 65% of individuals who have a hearing impairment are under the age of 65 years (Kochkin, 2005a). The subjects included in this retrospective study who had previously worn hearing aids may have accepted their hearing loss more so than the new hearing aid users in the study. In turn, hearing aids may be seen as a more valid form of treatment to them than to new hearing aid users; therefore, previous hearing aid users may perceive more value in hearing aids. One subject, a new hearing aid user, indicated that preference was for the entry-level hearing aid technology in comparison to advanced level technology; however, this preference was made, at least in part, by cost, as the individual reported that the levels of technology were "equal based on cost." It is possible that the decreased value of hearing aids by this subject was caused in part by stigma. Unfortunately, the factor of stigma cannot be separated entirely from these data. The final subject who preferred a lower level of technology trialed advanced and mid-levels and reported that although speech was clearer with the advanced technology, he preferred the mid-level as music more was more enjoyable. This may be due to the processing of the hearing aids, as they provide much of the amplification above 1000 Hz, where important speech cues are, and much music information is below 1000 Hz (Chasin, 2009). Many of the added features in hearing aids to help with speech understanding are not necessary while listening to music; in fact, they may actually be detrimental. Many audiologists employ a separate music program in the hearing aids, for use specifically when listening to music. Typically, such programs offer more gain in the lower frequencies than would a speech program, essentially linear settings, and no additional features (i.e., directionality, noise reduction, etc.) (Chasin, 2009). No music program was added into either the advanced or the mid-level hearing aids, which may explain the subject's preference.

Twenty-one percent of subjects purchased a lower level hearing aid technology than was preferred. All of them cited cost as a primary concern. Financial concerns are present with over half of hearing aid candidates (Kochkin, 2004), and it is therefore imperative for audiologists to be aware of this in the population being served so proper informational counseling can be provided. Therefore, the data collected in this study is useful clinically at Ohio State, as patients can be counseled on the amount of benefit perceived in relation to cost that is reflective of the population served at The Ohio State Clinic.

It should be made clear that these data do not indicate that every hearing aid candidate is a candidate for advanced level features; as audiologists the many different aspects of the candidate's life needs to be taken into consideration when discussing amplification. These include hearing loss, working memory, listening environments, activity level, etc. Preference alone should not determine the recommendations made to patients. However, these data give validity to the advanced features in higher levels of hearing aid technology; therefore, when appropriate these technologies should be considered.

Limitations and Future Studies

Limitations are inherent with retrospective studies, as some factors cannot be controlled for during the data collection process. Therefore, the following aspects of a prospective study are called for in future research. A prospective study with the aim of addressing hearing aid technology preference among individuals with hearing loss would be beneficial in that control during data collection can take place. A prospective study with a large sample size of individuals with varying degrees of hearing loss, distributed in categories such as “blinded” and “not blinded,” could provide valuable information on preference of hearing aid technology while controlling for factors such as knowledge of technology trialed, as well as determining the relationship between age and severity of hearing loss to technology preference. Unfortunately, the current retrospective study does not address these relationships as each subject in the study did not trial every level of hearing aid technology and many subjects who trialed the same levels of hearing aid technology were of the same age and severity of hearing loss. Therefore, the information obtained with such statistical data could not be appropriately interpreted in a manner that relates to clinical relevance. However, this is considered to be a clinical reality. Often, a patient will present in a clinical setting with financial limitations, reporting that the most advanced level of hearing aid technology is financially out of reach, regardless of trial or preference. Although this patient may find added benefit and even prefer the advanced level hearing aid, insisting trial of the most advanced level hearing aid technology may prove to be a fruitless endeavor, and may even introduce an ethical issue. A long term prospective study of this nature could also determine if a relationship between hearing aid technology level purchased and compliance exists. If such a relationship exists, meaningful clinical information can be obtained in terms of counseling and follow-up care. Quantitative data in respect to outcome measure changes between levels of hearing aid technology may also provide clinical insight. Since patients will not comply with hearing aid recommendations if they do not perceive benefit, quantifying the changes may improve compliance, assist with counseling, and provide additional insight into preference of hearing aid technology in relation to features of the hearing aids. With such data it may be possible to demonstrate which features of the advanced hearing aids provide additional benefit to patients. This may be especially true for an outcome measure where individuals list the difficulties they notice most, such as the COSI. Unfortunately, mean data in regards to changes on the COSI could not be measured in the present retrospective study as not every subject trialed every level of hearing aid technology, and COSI data were not obtained, or stored, for every trial the subjects did complete.

A second limitation of a clinical nature must be addressed in this study. Although different levels of hearing aid technology were addressed in this retrospective study, information was collected with the use of two generations of hearing aids. Therefore, the effect of better signal processing on preference cannot be ruled out. However, this is a clinical reality, as hearing aid technologies often are released separately. Although this is a limitation to this study, it is also reflective of clinical practice. It is because of such clinical realities that measurements of benefit and preference can be limited retrospectively.

Although the relationships between age, severity of hearing loss, and COSI improvement to preference were not addressed in this retrospective study, this does not negate the importance of the information obtained. Ninety-one percent of subjects included in this retrospective study preferred the highest level of hearing aid technology they demonstrated and 79% purchased it. The 21% who did not cited cost as the primary deciding factor. Thus, 79% of subjects purchased their preference even though their preference was more expensive. These individuals opted to pay more for higher levels of hearing aid technology, based on preference alone. Although the exact amount of benefit provided by the additional features in advanced level hearing aids cannot be measured functionally in a manner that equates to real world listening environments, the data obtained in this study give credit to the belief that higher levels of hearing aid technology provide benefit to individuals with hearing loss, benefit noticed by the user. It is a belief by some in the audiology community that higher levels of hearing aid technology do not provided added benefit in comparison to lower levels of hearing aid technology. Based on subject preference alone, this statement is incorrect; and since hearing aid compliance is dependent on patient perception of hearing aid benefit, it is this researcher's belief that preference is enough to refute such statements. Audiologists, along with other health care providers, are required to demonstrate treatment efficacy (Uriate et al., 2005), and the results of this retrospective study indicated validation of more advanced levels of hearing aid technology. Therefore, these technologies should be considered when determining appropriate hearing aid devices for hearing impaired individuals routinely in clinical practices.

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